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Accelerated drying of wet boots

W.R. Dyck

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Abstract

Much has been written about materials known as "super absorbers" with respect to their ability to keep the skin dry in the presence of moisture. One such material is sodium polyacrylate. Because recent field trials with Canadian Forces soldiers have reconfirmed that donning wet combat boots is very uncomfortable, a study was done to assess the efficacy of using sodium polyacrylate based drying pads to dry wet combat boots in a simulated field environment. The boot used in this study was non-insulated, had a water resistant full grain leather upper, and lined with a waterproof, water-vapour permeable membrane covered with a nylon inner liner. A dry boot and pad were weighed and the boot was wetted inside and out. After the boot was removed from the water and the water poured out of the boot, a drying pad was placed inside the boot and the entire system was placed on electronic scales connected to a computer. The wetting characteristics of the pad and the drying characteristics of the boot were monitored and analysed at two temperatures, 15.8°C and 23.3°C. The pad absorbed water very quickly, within about 30 minutes. It does not, however, pick up very much moisture, 62.9 to 78.9 grams. It is postulated that a soldier will require at least 4-6 pads for drying his/her wet weather boots in the field.

Résumé

De nombreux documents sur les matériaux dits « super absorbants » traitent de la capacité de ces derniers à garder la peau sèche en présence d'humidité. Le polyacrylate de sodium est un de ces matériaux. Puisque de récents essais en conditions réelles avec les soldats des Forces canadiennes ont reconfirmé qu'il est très inconfortable de chausser des bottes de combat trempées, une étude a été menée afin d'évaluer l'efficacité de tampons de séchage à base de polyacrylate de sodium pour sécher les bottes de combat en conditions de campagne simulées. La botte utilisée pour cette étude n'était pas isolée et comportait une tige en cuir pleine fleur imperméable doublée d'une membrane imperméable et perméable à la vapeur d'eau revêtue d'une doublure intérieure de nylon. Une botte sèche munie d'un tampon a été pesée et la botte a ensuite été trempée de part en part. Elle a été retirée de l'eau et l'eau, vidée de la botte. Un tampon de séchage a été placé à l'intérieur de la botte et le système a été déposé au complet sur une balance électronique reliée à un ordinateur. Les caractéristiques de mouillage du tampon et les caractéristiques de séchage de la botte ont été contrôlées et analysées à deux températures, 15,8 °C et 23,3 °C. Le tampon a absorbé l'eau très rapidement, en moins de 30 minutes environ. Cependant, il n'absorbe pas beaucoup d'humidité (entre 62,9 et 78,9 grammes). Il faudrait à un soldat de 4 à 6 tampons pour sécher ses bottes de pluie sur le terrain.

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Executive summary

A conclusion drawn from recent boot trials is that no soldier likes wet feet or wet footwear. It was shown that having dry feet is even more important than having warm feet. Some boots were tested in cooler weather and incorporated a waterproof, water vapour permeable liner designed to keep the foot dry. In this temperature range, water combined with cold temperatures could result in severe cold injuries. Other boots were tested in warmer weather and although wet foot conditions were more tolerable, subjects still felt uncomfortable and reported the belief that their feet were predisposed to blisters. No matter how careful one is, the layer of the footwear system worn next to the skin will get wet either from external water sources coming in over the top of the boot or through the boot, or from sweat generated within the boot.

Since natural drying of boots in the field, overnight, is not fast enough, and since drying boots on equipment giving off great amounts of heat may damage the boots, a study was done to assess the efficacy of using drying pads made of "super absorber" based materials to dry wet combat boots in a simulated field environment.

The boot used in this study was non-insulated, had a water resistant full grain leather upper, and lined with a waterproof, water-vapour permeable membrane covered with a nylon inner liner. The dry boot and pad were weighed and the boot was wetted inside and out. After the boot was removed from the water and the water poured out of the boot, a drying pad was placed inside the boot and the entire system was placed on electronic scales connected to a computer. The wetting characteristics of the pad and the drying characteristics of the boot were monitored and analysed three times at two temperatures, 15.8°C and 23.3°C. The pad absorbed water very quickly, within about 30 minutes, and dried to its dry weight within 24 hours. It does not, however, pick up very much moisture, 62.9 to 78.9 grams, unless the user intervenes, i.e. reorientation of the boots and pads or insertion of new pads. If the pad ever does get very wet e.g. immersion, it will take more than 6 days to dry.

If the soldier is allowed to, and wants to use such drying aids, then it is postulated that each soldier will require at least 4-6 pads for drying his/her wet weather boots in the field. This is assuming the pads can be dried (and kept dry) within about 20 hours (or less, depending on when the drying process actually started), so they can be reused if necessary.

Dyck, W.R. 2002. Accelerated drying of wet boots. DRDC Toronto TR 2002-196. Defence R&D Canada Toronto.

Sommaire

De récents essais menés sur des bottes ont permis de conclure qu'aucun soldat n'aime avoir les pieds mouillés ni porter des articles chaussants trempés et qu'avoir les pieds au sec est encore plus important qu'avoir les pieds au chaud. Certaines bottes munies d'une doublure imperméable et perméable à la vapeur d'eau conçue pour garder les pieds secs ont été testées par temps froid. Dans cette plage de températures, l'eau combinée aux températures froides peut causer de graves lésions dues au froid. D'autres bottes ont été mises à l'essai par temps chaud et, bien que les conditions de pieds mouillés étaient plus tolérables, les sujets ressentaient tout de même un inconfort et ont signalé qu'ils croyaient que leurs pieds étaient ainsi plus vulnérables aux cloques. Peu importe les précautions, la couche du système de chaussure contre la peau devient mouillée à cause de l'eau qui entre de l'extérieur par le haut de la botte ou à travers la botte ou à cause de la transpiration produite à l'intérieur de la botte.

Comme le séchage naturel des bottes sur le terrain, pendant la nuit, n'est pas suffisamment rapide et comme le séchage des bottes à l'aide d'équipement produisant une grande quantité de chaleur peut endommager les bottes, une étude a été menée afin d'évaluer l'efficacité de tampons de séchage fait de matériaux à base de « super absorbant » pour sécher les bottes de combat trempées en conditions de campagne simulées.

La botte utilisée pour cette étude n'était pas isolée et comportait une tige en cuir pleine fleur imperméable doublée d'une membrane imperméable et perméable à la vapeur d'eau revêtue d'une doublure intérieure de nylon. La botte sèche munie d'un tampon a été pesée et la botte a ensuite été trempée de part en part. Elle a été retirée de l'eau et l'eau, vidée de la botte. Un tampon de séchage a été placé à l'intérieur de la botte et le système a été déposé au complet sur une balance électronique reliée à un ordinateur. Les caractéristiques de mouillage du tampon et les caractéristiques de séchage de la botte ont été contrôlées et analysées trois fois à deux températures, 15,8 °C et 23,3 °C. Le tampon a absorbé l'eau très rapidement, en moins de 30 minutes environ, et a séché jusqu'à son poids à sec en moins de 24 heures. Cependant, il n'absorbe pas beaucoup d'humidité (entre 62,9 et 78,9 grammes), à moins que l'utilisateur intervienne, c.-à-d. réorientation des bottes et des tampons ou insertion de nouveaux tampons. Si le tampon devient très mouillé (par exemple, immersion), il lui faudra plus de six jours pour sécher.

Si un soldat veut utiliser de tels dispositifs de séchage, et s'il a l'autorisation de le faire, alors il lui faudrait de 4 à 6 tampons pour sécher ses bottes de pluie sur le terrain. Cette supposition implique que les tampons peuvent être séchés (et gardés au sec) en moins de 20 heures environ (ou moins, selon le moment où le processus de séchage a réellement commencé) de manière à pouvoir être réutilisés si nécessaire.

Dyck, W.R. 2002. Accelerated drying of wet boots. DRDC Toronto TR 2002-196. Defence R&D Canada Toronto.

Table of contents

List of figures

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Introduction

Over the past few years, several studies of prototype, commercial and military boot systems have been performed with the assistance of members of the Canadian Forces (CF) Land Force (LF). Soldiers were asked to participate in controlled and uncontrolled field trials lasting 2-3 months. Controlled trials consisted of all trial personnel performing the same procedures, at the same time, within the same conditions while being observed by personnel trained in human factors evaluations. The uncontrolled trials consisted of wearing the boots during regular duties and no trial personnel present (unobserved). Subjects were asked to complete questionnaires and participate in focus groups through which their opinions on the footwear systems being studied could be elicited.

One conclusion drawn from these trials is that no soldier likes wet feet or wet footwear [1-3]. Tack [1] concluded that having dry feet is even more important than having warm feet. Some boots were tested in cooler weather (-10°C to +15°C) and incorporated a waterproof, water vapour permeable liner designed to keep the foot dry. In this temperature range, water combined with cold temperatures could result in severe cold injuries [4]. Other boots were tested in warmer weather (>15°C) and although wet foot conditions were more tolerable, subjects still felt uncomfortable and reported the belief that their feet were predisposed to blisters [5]. No matter how careful one is, the layer of the footwear system worn next to the skin will get wet either from external water sources coming in over the top of the boot or through the boot, or from sweat generated within the boot. The feeling is not liked and many anecdotal methodologies exist for drying boots quickly in the field.

Sodium polyacrylate is a chemical "super absorber" found in most disposable diapers, water-retaining gels in houseplants, and in toys sold as small models of animals etc., that "grow" in water. Sodium polyacrylate is made by polymerizing a mixture of sodium acrylate and acrylic acid [6]. The difference between the Na^+ ion concentration inside the polymer network and the solution in which it is immersed generates an osmotic pressure that is alleviated as water diffuses into the polymer. The amount of liquid that can be absorbed depends on the ionic strength of the solution. For example, this polymer can absorb 800 times its own weight of distilled water, 300 times its own weight in tap water, but only 60 times its own weight in urine (~0.9% NaCl).

Since natural drying of boots in the field, overnight, is not fast enough, and since drying boots on equipment giving off great amounts of heat may damage the boots, a short study was undertaken to determine the efficacy of using a commercially available product described as a "super absorber" on combat boots in the field.

Method

Two pads, consisting of a sealed cotton wicking material containing a white sodium polyacrylate powder, were obtained. Each pad was rectangular in shape and weighed approximately 100 g. The length and width of the pad were such that they were easily placed along the insole of an average-sized boot.

The boot used was a Mondopoint size 270/102, non-insulated boot with a water resistant full grain leather upper and a comfort collar. The boot contained a waterproof, water-vapour permeable membrane covered with a nylon inner liner.

The dry boot and pad were each weighed using an electronic scale (Sartorius Corp. 131 Heartland Blvd., Edgewood N.Y. 11717) accurate to 0.01 g and with a range up 0.00 to 4100.00 g. The boot was placed in a small container and filled with tap water until overflowing. The container was then filled with water up to the comfort notch at the ankle on the outside of the boot. After a 5 minute wait, the water was poured out of the boot, and three stacks of three paper towels formed into a ball were used to quickly dry the insides of the boots, to get rid of any free standing water at the bottom of the inside of the boot, as one might do in the field with a limited supply of drying materials. The wet boot was again weighed to determine the amount of water retained by the boot.

A dry pad was then placed along the inside of the bottom of the wet boot, and the boot plus pad were placed on the scales and weighed. The scales were connected to a computer via a proprietary cable, and using a simple basic program developed in-house, the scales were interrogated by the computer every 15 or 20 minutes (programmed at the start of a run), and the weight of the boot-plus-pad-plus-water was digitally recorded in a data file. Once the computer recorded a weight (monitored on screen) the pad was quickly and carefully removed from the boot, and the weight of the boot-plus-water (no pad) was recorded manually. The pad was then reinserted into the boot, and again placed on the scales. At first, the program was allowed to run for about 24 hours, but later it was determined that a 2 hour period was sufficiently long to capture the effect.

This experiment was done three times at two temperatures and results shown are the means of the three runs. The first group of experiments was done in a temperature controlled room set to 15°C and 25% relative humidity (R.H.), while the second group of experiments was done at 25°C. The temperature and humidity were monitored in the immediate vicinity of the experimental set-up using a Vaisala Type HMP233 transmitter (Vaisala Inc, 100 Commerce Way, Woburn, MA 01801-1068) and recorded at the start of each test. At the conclusion of each test, the real-time recorders of temperature and relative humidity for the chamber were checked for ranges of fluctuations of values during the test.

As a final test, a dry pad was weighed, and then completely immersed in tap water for approximately 60 min. At 6 time intervals (T = 1, 3, 7, 15, 30 and 60 minutes) during the immersion, the wet pad was quickly and carefully removed from the container (excess water was allowed to drain from the pad-plus-water) and weighed. After the final interval, the pad-

plus-water was placed on the scales and allowed to dry at room temperature (23°C) for 6 days while the weight was monitored using the computer system mentioned previously.

Results

The temperatures for the three cool tests were 15.9, 16.2, and 15.3°C and for the three warm tests were 23.7, 23.7, and 22.5°C, averaging out to 15.8°C and 23.3°C. The temperature range of operation by subjective observation of the chamber recorders was approximately 16°C and 24°C ± 1°C. The relative humidity typically cycled between 20% and 30%, and for brief periods, would occasionally jump to almost 40%.

The system drying results 15.8°C and 23.3°C are shown in Figure 1 and the pad results in Figure 2 in more detail. The amount of water in the boot is determined as the difference of the weight recorded (manually) of the boot-plus-water alone and the dry boot weight. Since the computer automatically measures the total amount of water in the boot-plus-pad, the amount of water in the pad is calculated to be the difference between the computer total water reading and the calculated water in the boot.

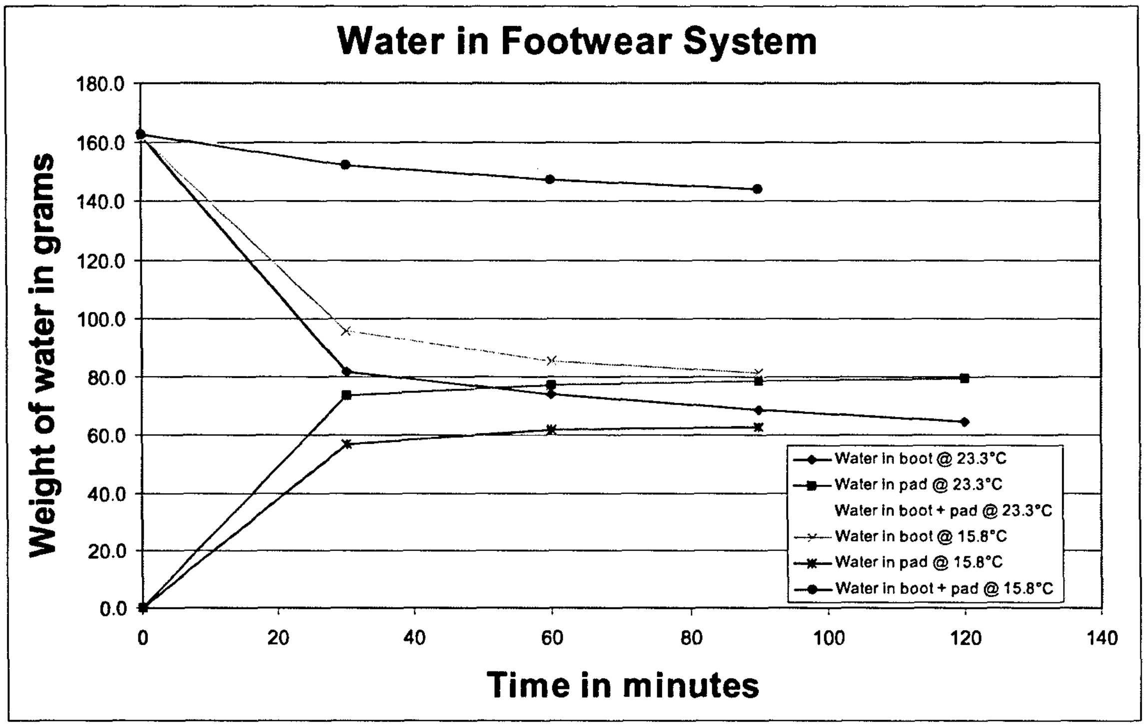

Figure 1. *Graph showing the location of water in the footwear system during the drying process. Each point is the mean of three runs.*

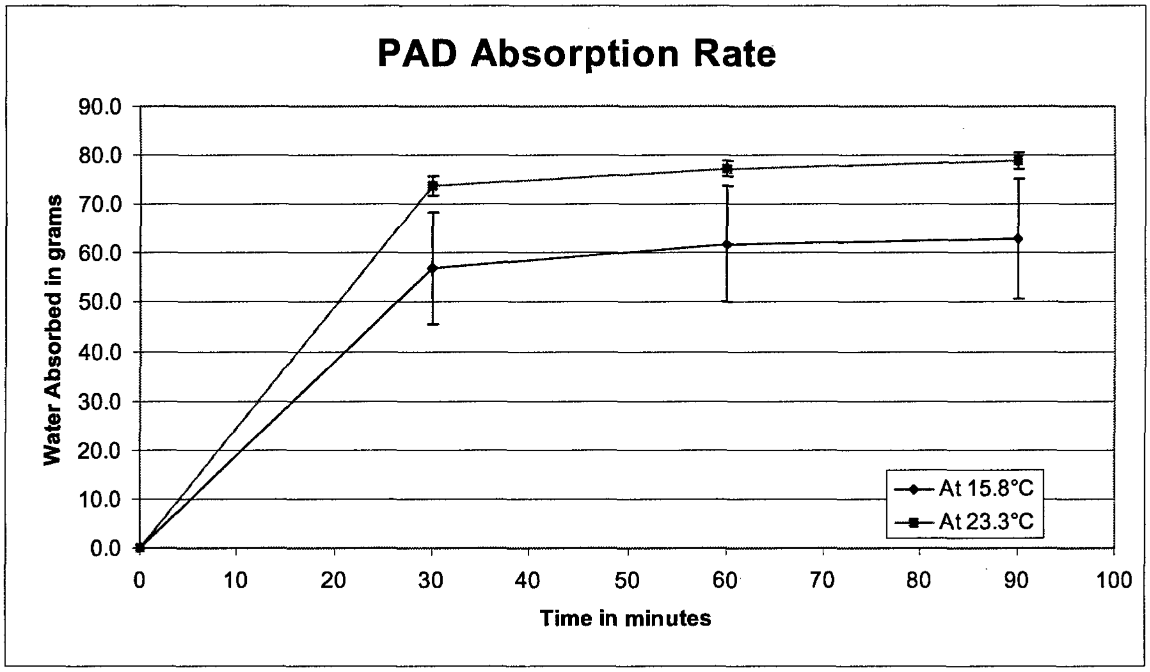

Figure 2. *Graph showing the water uptake curves of the pad at the 2 different temperatures. Each point is the mean of three runs and the error bars show standard deviations.*

The pad wetting result is shown in Figure 3 and the drying result is shown in Figure 4.

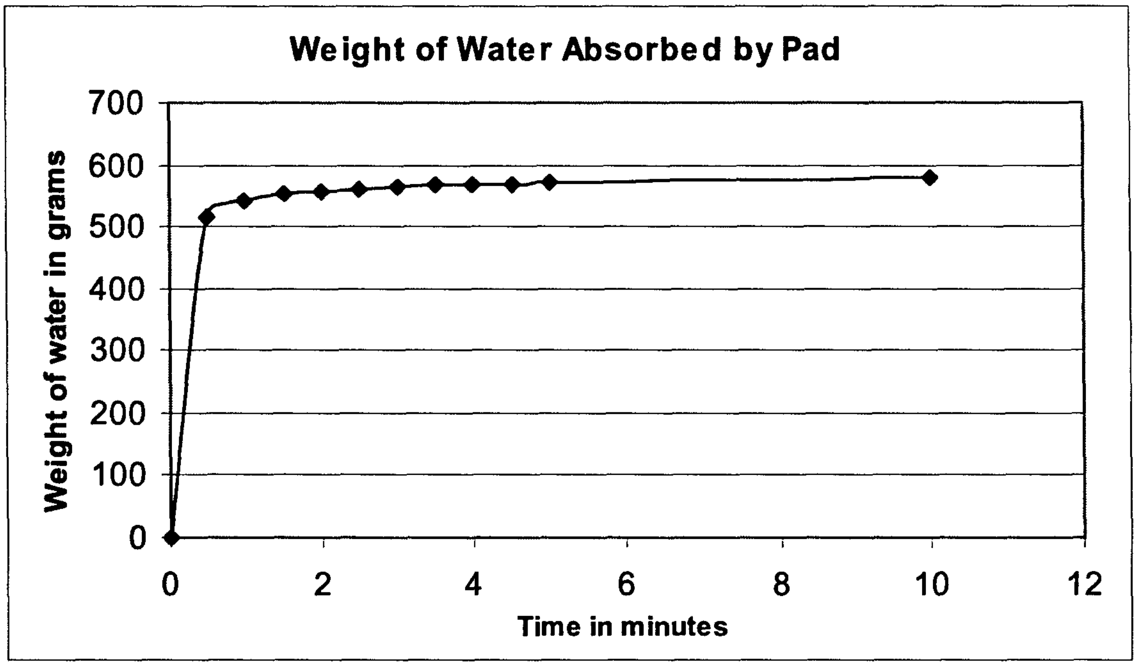

Figure 3. *Water uptake of a pad weighing 102.27 g.*

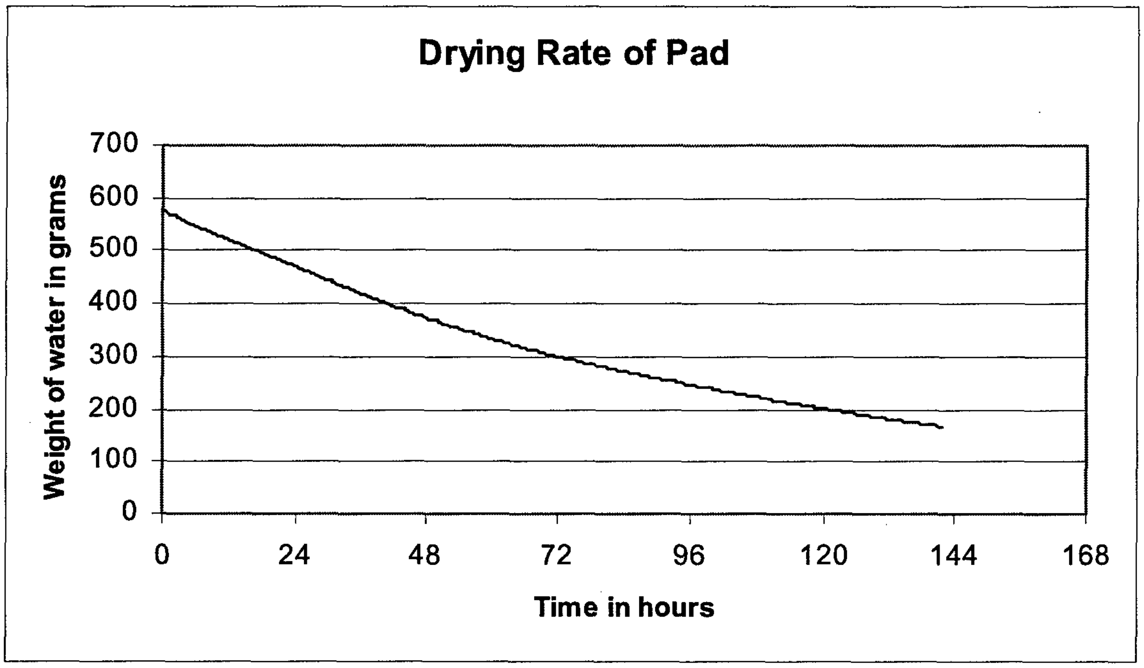

Figure 4. *Drying curve of the pad immersed in water for 10 minutes (see Figure 3).*

Discussion

As can be seen in Figures 1 and 2, much of the effect of water absorption of the pad has taken place in the first 30 minutes. Contrary to the claims of products containing sodium polyacrylate of being able to absorb many times their own weight in water, a product in this configuration used in this manner absorbs only a percentage of its weight. When totally immersed in water, however, the pad absorbs almost six times its weight in only minutes (Figure 3). Since the first tests exposed only a portion of one side of the pad to a wet surface in the bottom of the boot, it appears that the amount of water absorbed depends on contact surface area. The difference in the curves (Figures 1 and 2) seems to indicate that the amount the pads absorb is also temperature dependent. In the warmer temperature, the pad absorbs approximately 78.9 g water (or 80.4% of its weight) whereas at the cooler temperature, the total is only 62.9 g water (or 62.0% of its weight). A t-test performed at each sample time indicated, however, that the difference was not statistically significant for $p<0.05$.

Following the first test, which was allowed to run for 1650 minutes (27.5 hours) three personnel were asked for a subjective opinion of whether the boot was dry enough to be worn comfortably. Each put their hand in the boot and felt the liner in several places and all three rated the dry comfort as unacceptable. Two personnel were military and remarked they would wear the damp boots if that was all they had (both had done so in the past), but would not if they had a choice.

If wet boots, after only a quick attempt at drying, retain approximately 160 g of water (Figure 1), and the pads absorb anywhere from 50 to 77 g water (depending on the temperature), one would need about 2 to 3 pads to dry one boot, assuming the absorption is not amount/concentration dependent, and all the moisture was present in the bottom of the inside of the boot against which the pad was placed. This would require personnel to carry a minimum of 4 to 6 pads with them for their boots alone. This also assumes that the pads will dry and be ready for reuse by as early as the next evening, or even more pads would be required if the boots needed to be dried the following night and the pads were not dry enough to be reused.

The pads were dried naturally at room temperature because there was typically more than 3 or more days between experiments. It was found that the pads had returned to their original dry weight within a day. As can be seen in Figure 4, the drying curve of the saturated pad is exponential, the equation of which was determined as:

$$A = A_O * \exp(-0.00015 * T), \text{ where}$$

A is the water in the boot in grams, Ao is the amount of water in the boot at the outset in grams, and T is the drying time in minutes.

The exponential shape is likely due to the fact that the outermost layers of material dry quickly while the innermost layers (further away from the ambient air) take longer to diffuse the moisture through the outer layers to evaporate into the air. This model of evaporation of

the pads is not enough to explain the return to dry weight within a day. Two reasons for the faster drying time are suggested. The process of preparing the pads for reuse also involves manually messaging the bags to break up the small lumps created by the absorbed water, increasing the evaporative surface area, accelerating the drying process. Also, the cotton wicking material of the bag has also absorbed some moisture and has a much faster drying curve.

Assuming the Land Force will be allowed to use such accelerated drying aids, two scenarios can be envisioned. Both scenarios further assume that the boots the soldiers are wearing have become wet, are still wet enough the next morning to make them uncomfortable to wear, and one pad is not sufficient to get them dry enough to wear. One use of these pads would be to place one in each boot, then change orientation of the boot every 30 minutes and either put in a fresh pad, or turn the current pad over (turn only once for each pad) so that the dry surface of the pad is making contact with a different wet inner surface of the boot. This could take 2-3 reorientations per boot, lasting 1.5-2.0 hours. The second potential use of the pads would be to place all 3 pads into each boot at once, making contact with as much of the inner surface as possible. Both these methods then require the pads be exposed and dried over the course of the following day, messaged as required, for possible reuse the next evening. Neither of these two methods was actually tested to see how much more efficient these methods would be.

It is also important to remember that these tests were done using tap water. Thus if the boot got wet by water getting in from an external source (e.g. rainwater or fresh stream) over the top of the boot, the pads might absorb more water. As discussed in the introduction, this amount is very likely reduced if the water in the boot is as a result of profuse sweating which has a much higher salt content.

Conclusions

Fortunately, the sodium polyacrylate-filled pads pick up moisture quickly, i.e. within about 30 minutes. Unfortunately, they do not pick up very much moisture, 62.9 to 78.9 grams, without user intervention, i.e. reorientation of the boots and pads or insertion of new pads. The slight wetting of the surface of the pads is, however, more conducive to quicker drying (less than 24 hours) compared to wetting by total immersion (longer than 6 days).

If the soldier is allowed to, and wants to use such drying aids, then it is postulated that each soldier will require at least 4-6 pads for drying his/her wet weather boots in the field. This is assuming the pads can be dried (and kept dry) within about 20 hours (or less, depending on when the drying process actually started), so they can be reused if necessary. More tests are required, however, to confirm the efficacy of using multiple pads.

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14. ABSTRACT

(U) Much has been written about materials known as "super absorbers" with respect to their ability to keep the skin dry in the presence of moisture. One such material is sodium polyacrylate. Because recent field trials with Canadian Forces soldiers have reconfirmed that donning wet combat boots is very uncomfortable, a study was done to assess the efficacy of using sodium polyacrylate based drying pads to dry wet combat boots in a simulated field environment. The boot used in this study was non-insulated, had a water resistant full grain leather upper, and lined with a waterproof, water-vapour permeable membrane covered with a nylon inner liner. A dry boot and pad were weighed and the boot was wetted inside and out. After the boot was removed from the water and the water poured out of the boot, a drying pad was placed inside the boot and the entire system was placed on electronic scales connected to a computer. The wetting characteristics of the pad and the drying characteristics of the boot were monitored and analysed at two temperatures, 15.8°C and 23.3°C. The pad absorbed water very quickly, within about 30 minutes. It does not, however, pick up very much moisture, 62.9 to 78.9 grams. It is postulated that a soldier will require at least 4-6 pads for drying his/her wet weather boots in the field.

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15. KEYWORDS, DESCRIPTORS or IDENTIFIERS

(U) Boots; drying; super absorbers; sodium polyacrylate.

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